A Revision of our Lower Eocenes.

By Geo. F. Harris, F.G.S.

The Lower Eocene formations of the British Isles are situated in four different regions—1. The London basin ; 2. The Hampshire basin ; 3. The Isle of Mull and the neighbouring parts of Scotland ; and 4. The North-East of Ireland.

The principal subject of the present communication is the London basin, which is, roughly speaking, a triangular patch of clays, sands, and gravels, lying on the Chalk, and the edges of which extend in a westerly direction from Pegwell Bay (near Ramsgate) through Rochester, Croydon, Basingstoke, to Hungerford ; thence north-eastwards through Reading, Windsor, Watford, by Hertford and Woodbridge to the eastern part of Norfolk by Great Yarmouth. The estuary of the Thames occupies the site of a large portion of the beds which have been denuded by that river and by the sea on the eastern boundary of the basin in Essex, Suffolk, and Norfolk.

Many geologists have described portions of the area under consideration, amongst the earlier of which we might mention Mr. J. Parkinson, "Observations on Some of the Strata in the Neighbourhood of London and on the Fossil Remains contained in them" ('Trans. Geol. Soc.,' 1811, Ser. 1, Vol. i, p. 324) ; Rev. Prof. W. Buckland, "Description of a Series of Specimens from the Plastic Clay near Reading," &c. ('Trans. Geol. Soc.,' 1817, Ser. 1, Vol. iv, p. 277) ; Prof. Morris, "Observations on the Strata near Woolwich" ('Mag. Nat. Hist.,' Vol. viii, 1835, p. 356) ; "On the Strata usually termed Plastic Clay" ('Proc. Geol. Soc.,' Vol. ii, 1837, p. 551) ; Rev. H. M. De la Condamine, "On the Tertiary Strata and their Dislocations in the Neighbourhood of Blackheath" ('Q. J. G. S.,' Vol. vi, 1850, p. 440) ; Mr. N. T. Wetherell.

The general structure of the beds between the London Clay and the Chalk, however, in spite of the careful researches above mentioned, was but very imperfectly understood before Professor Prestwich took up the subject in great detail, and laid the results of his masterly observations before the Geological Society in the following three memoirs : Part I. "The Basement Bed of the London Clay" ('Q. J. G. S.,' Vol. vi, 1850,

p. 252); Part II. "The Woolwich and Reading Series" * ('Q. J. G. S.,' Vol. x, 1854, p. 75); Part III. "The Thanet Sands" † ('Q. J. G. S.,' Vol. viii, 1852, p. 235). These memoirs have been largely used in the works of subsequent observers. Sir Chas. Lyell wrote on "The Blackheath Pebble-Bed, and on Certain Phenomena in the Geology of the Neighbourhood of London" ('Proc. Roy. Inst.,' Vol. i, 1852, p. 164; and 'Edin. New. Phil. Journ.,' Vol. liii, p. 94); Mr. C. Rickman on "Fossil Remains from Tertiary Strata at Peckham and Dulwich" ('Geologist,' Vol. iii, 1860, pp. 151, 211), and on "The Lower London Tertiaries in the same Districts" ('Q. J. G. S.,' Vol. xvii, 1861, p. 6; 'Proc. Geol. Assoc.,' Vol. i, 1861, p. 106).

The next great series of works on the subject were those of Mr. Whitaker, whose several important memoirs—"On the Western end of the London Basin," &c. ('Q. J. G. S.,' Vol. xviii, 1862, p. 258); "The Tertiary Beds of Kent" ('Geologist,' Vol. vii, 1864, pp. 57, 157); and "On the Lower London Tertiaries of Kent" ('Q J. G. S.,' Vol. xxii, 1866, p. 404)—culminated in the standard work on the "Lower Eocenes of the Southern and Western Portions of the London Basin" ('Mem. Geol. Surv.,'‡ Vol. iv, Part I, 1872). This has been supplemented, as the north-eastern part of the basin was worked out, by short official memoirs, largely written by Mr. Whitaker, but also by Messrs. W. H. Dalton, F. J. Bennett, and J. H. Blake, by which our knowledge of that portion of the area has been very considerably augmented. Mr. H. M. Klaassen has minutely described a "Section of the Lower London Tertiaries at Park Hill, Croydon" ('Proc. Geol. Assoc.,' Vol. viii, 1883, p. 226), and Mr. E. T. Newton has added an appendix on a new species of *Perna*, and on *Coryphodon* remains from the Woolwich beds in the same section (*ibid.*, pp. 248, 250). Numerous other valuable papers will be found in our Proceedings. Mr. Starkie Gardner has written "On a Revision of the British Eocenes" ('Geol. Mag.,' Dec. II, Vol. ix, 1882, p. 466); "On the Section between

* 'With a Description of New Species of Shells,' by Prof. Morris, p. 157; 'Notes on the Entomostraca,' by Prof. T. Rupert Jones, p. 160; and A Note on the Fossil Plants from Reading,' by Dr. J. D. Hooker, p. 163.

† 'With a Description of Fossil Shells from the Lower Thanet Sands,' by Prof. Morris.

‡ Complete lists of references up to date will be found in this work.

Herne Bay and Reculvers" ('Q. J. G. S.,' 1883, pp. 197-210), and other memoirs.

Before attempting to give the views of the various authors referred to, let us get some idea of what the beds are like. We will commence by generalizing those in the western part of the area, working thence eastwards.

We find in the neighbourhood of Hungerford and Reading a very variable series of beds lying between a massive argillaceous deposit, known as the London Clay, and the Chalk. After examining a large number of sections in them, a sort of general sequence is made out, which may be indicated in the following manner:—

West of the London Basin.

1. Thick mass of clay (London Clay).
2. Shingles, sands, and clays.
3. Mottled clays and sands.
4. Shingles, sands, and clays.
5. Chalk.

No description can be drawn up which shall be applicable, even in a general sense, to all the sections in which beds 2 and 4 are seen. Sometimes a pebble bed underlies the London Clay, at the base of which is a series of more or less pure sands and clays, this being followed by mottled clay; whilst at others the pebble-bed is absent and a thick mass of sand occurs in its place. The mottled clay itself is by no means a massive sheet of clay of a certain thickness. It often does occur as a thick bed of clay of a red, green, and yellow mottled appearance; but it is just as often cut up by seams of sand; whilst occasionally, as in the railway cutting at Reading, it is in lenticular patches. Moreover, it is often found resting unevenly on the sands and shingle below, and now and then approaches to within six or seven feet of the Chalk. The sequence alluded to holds tolerably well until the neighbourhood of Epsom is reached, when bed 4 develops a thick mass of sand at its base. In this region also and to the south-westward a bluish-black clay makes its appearance above the mottled clay; but things do not begin to get very clear until Croydon is reached. We then find that the incoming of other beds renders the general sequence of the beds in the western part of the basin unrecognizable in

this district. A new order obtains, which might be thus expressed :—

*Croydon District.**

1. Thick mass of clay (London Clay).
2. Thick sand laminated in parts.
3. Very thick pebble-bed, with shell bed at the base.
4. Blue clays full of shells, mostly broken.
5. Mottled clay.
6. Clayey sand with pebbles, especially at the base.
7. Very thick sands.
8. Chalk.

These divisions hold good until we near Lewisham. We there find that the pebble-bed (3) has dwindled away to six inches in thickness, and that bed 2 has become more laminated, having thin clay partings throughout. Bed 4 becomes very much sub-divided, having sand and lead-coloured clay with lignite in its upper part. The mottled clay (5) requires the eye of faith to detect it in its proper place. Bed 6 has developed an enormous mass of shingle, rather sandy and argillaceous at its base.

Woolwich District.—On reaching Charlton the relation of the London Clay to the thick laminated sand (bed 2) is not very clear, by reason of the absence of a good section of the junction. But we find a very thick pebble-bed, which probably corresponds with bed 3, in the Croydon district, resting unevenly on a bed of sand which lies on the blue clays (bed 4). The mottled clay, as at Lewisham, is indistinctly represented.

On Blackheath a very thick pebble-bed is found; but, so far as I am aware, no fossils have been found in it at that place. It is much to be desired that the exact position of this pebble-bed should be ascertained with reference to the other beds in the district. It is generally stated that its horizon is immediately under the basement bed of the London Clay, and that it occasionally eats its way through the blue clays (bed 4), and lies unconformably to the beds beneath, examples being cited from Greenwich, Abbey Wood, Sundridge tunnel, &c. At Bostal Heath, near Plumstead,

* See Klaassen, 'Proc. Geol. Assoc.,' Vol. viii, 1883, p. 248, for details.

there can be no doubt that a pebble-bed is found on the side of the hill, resting on bed 6. The same might be said with regard to it at other places between Plumstead and Erith. When we arrive at the latter place we find that the succession of the beds is the same as at Charlton. The mottled clay is more pronounced, but bed 6 is not so well shown. It is mostly a sandy pebble-bed.

Upnor District.—At Upnor, near Rochester, there are good exposures from the London Clay to the middle of the Thanet beds, whilst the Chalk may be seen a short distance to the south of the largest sections. The whole of the beds dip at a low angle to the northwards. Their sequence is somewhat different from that at Erith, or, rather, the characters of some of the beds are changed. We may indicate it by the following :—

Upnor District.

1. Thick massive London Clay, with pebbles at the base.
2. Light buff sand, with scattered pebbles.
3. Bed of well-rounded pebbles, with shells.

3*a*. Thick sandy bed, with bands of clay in places.

4. Blue clays, with broken shells and very thin streaks of sand.
5. *a*. Laminated sand and clay.
   b. Fine white sand.
   c. Lilac-coloured sandstone, not very compact. Lignitic.
6. Thick mass of false-bedded sand, with thin pebble-bed at base.
7. Very thick buff-coloured sand.
8. Chalk.

A comparison of this section with that at Croydon will show that the general order of succession is practically the same. The principal difference is that the mottled clay is here replaced by other beds, included under 5. It is useful to notice the persistence of the lilac-coloured sandstone in passing. This bed, which is lignitic in places, is met with in the same position many miles from Upnor, and serves as a guide in working out the sequence. It has been seen *in situ* near Green Street Green (on the Swanscombe Park outlier, about half way between Erith and Upnor); on the Cobham outlier; near Sittingbourne, and at many other places, some of which will be hereafter mentioned. There are very few

sections of any importance between Upnor and Boughton-under-Blean, five miles west of Canterbury, except near Sittingbourne, where beds 2, 3, 3*a*, 4, and 5 are seen, presenting nearly the same features as at Upnor.

Canterbury District.—The sections at Boughton are not so easily disposed of, and it will be seen that I differ from previous observers in the explanation of the divisions into which the beds should be placed. Beds 2 and 3 occur, but not quite as at Upnor. In a pit near the 50th milestone on the London road * a series of sandy clays of a dark colour occur, cut up by frequent thin beds of whitish-yellow and green sand (causing the sandy clay to assume lenticular shapes in some places). The base of this bed is very dark, almost black, and ferruginous, and rests on a bed of greenish-brown sand. The general appearance of this bed is such as to suggest that it is the equivalent of the blue clays, with broken shells and thin, sandy streaks (4) at Upnor. This does not hitherto appear to have been recognized, and the result is that the bed has been placed higher in the series than is the bed 4 alluded to at Upnor. Its position, with reference to underlying beds, is exactly the same in the Boughton and Upnor sections. For instance, 5 *a*, *b*, and *c* occur, and are very easily recognized, the lilac-coloured sandstone being present. Between 5 *b* and *c* a very thin pebble-bed occurs. Beds 6 and 7 are seen farther down the road, and the whole succession is proved by many sections near the outcrop of the main mass of Lower Tertiaries.

We next come to Canterbury, where we find bed 2, a light buff sand, rather ferruginous at the base (the remains, perhaps, of 3*a*), and with a thin bed of small pebbles. Bed 4 is very ferruginous and sandy. Beds 5 *a* and *b* have nearly thinned out, there being only slight indications of 5*b*, and the thin pebble-bed which occurs at Boughton between 5 *b* and *c* is also present, and contains pieces of the lilac-coloured sandstone, 5*c*. Beds 6 and 7 are as usual, but a bed of argillaceous matter is found at the base of the latter. This we will call 7*a*.

Herne Bay District.—The next section claiming our attention is the finest exposure of the Lower Eocenes in the London basin, viz., between Herne Bay and Reculvers. We there find that bed 1 is

* See 'Mem. Geol. Surv.,' Vol. iv, Part I, p. 267.

present in force, with a few pebbles, and much lignitic matter at its base, as usual. Bed 2 is well developed, whilst 3 and 3*a*, as might have been expected from the foregoing remarks, have disappeared. Bed 4 is present, perhaps, in the shape of a thin deposit of clay and sand, much iron-stained as usual, whilst the pebble-bed below it (in 5) has thickened out. This pebble-bed is much divided up in places by lenticular patches of sand, and both it and bed 4 are liable to vary in thickness. Beds 6 and 7 are clearly shown, and 7*a* occurs in a well-section at Reculvers. At Pegwell Bay we get 7 and 7*a* in a good exposure.

We have now roughly described the beds which occur between the London Clay and the Chalk, from Hungerford to the east of Kent. It now remains for me to say a few words respecting the exposures of these beds in Hertford, Suffolk, and Norfolk. There are some very good sections about Watford, and the general sequence, although not strictly comparable, is like that in the western part of the basin (see p. 42), viz., a mottled clay between two beds of sand, clay, and shingle. I have not seen the exposures in Suffolk and Norfolk. Much of the beds is covered up by newer deposits. It is interesting to note that the officers of the Geological Survey, however, have described in the neighbourhood of Ipswich the true mottled clay, with sand, &c., both above and below it, in many sections, the principal of which, perhaps, is to the north of Bramford Station.* The sands above the mottled clays generally appear to be very well developed, and contain pebbles in this district.

We have now to consider briefly the palæontology of the different beds. Taking the western part of the basin first, we shall find that 4 (p. 42) is decidedly marine in character. It contains hardly anything but marine fossils, and these, with the exception of *Ostrea* and sharks' teeth, are rare. In the vicinity of Epsom certain of the beds comprised within it contain tube-like markings. Anyone familiar with the "tubes of annelids," found in such great abundance in the Belgian Lower and Middle Eocenes, will have no difficulty in recognizing them as such. Bed 6, in the Croydon and Upnor sections, is a further development of this bed 4, and, as will be remembered, the same bed (6) is found at Herne Bay.

* 'Geol. of Ipswich, Hadleigh, and Felixstow,' by W. Whitaker, B.A., F.G.S., &c. (1885), p. 14.

Throughout its extent it is marine, being in the last mentioned section replete with fossils, especially at the base, and no doubt can possibly creep in as to its origin. We may mention that exactly the same may be said of bed 7, which is very fossiliferous at Pegwell Bay, Herne Bay, and Upnor, and in which one or two marine shells have also been obtained from Erith * and Charlton. Retracing our steps to Reading, we find that bed 3 (p. 42) contains a fine flora at its base. So far as I am aware, no other fossils have been obtained from the mottled clay, so we have only to judge of its origin from the character of the deposit. It is generally admitted to be of fresh-water origin. The blue clays, bed 4, from Croydon to Upnor contain mostly fresh-water and estuarine fossils, such as *Cyrena*, *Cerithium* (*Potamides*), *Paludina*, *Melania*, &c. A few stray marine genera creep in, and a thick oyster bed is a common feature. The fossils, no less than the character of the beds, lead us to believe that they were deposited in the estuary of a river, where the sea and fresh water alternately gained the ascendancy over each other. A point to which I would particularly draw attention is that what I believe to be bed 4 in the section at Boughton-under-Blean (p. 45) has produced a rather more than usual abundance of marine shells. † We still find the estuarine *Melania*, *Cerithium*, *Cyrena*, &c., but they are accompanied by such well-known marine genera as *Aporrhais*, *Pyrula*, *Astarte*, *Cardium*, *Corbula*, *Cyprina*, *Cytherea*, *Panopæa*, &c. It would, therefore, appear that as the bed 4 goes eastwards it becomes less argillaceous and more marine in character. At Herne Bay this bed, like the pebble-bed below it, contains only sharks' teeth. The blue clays referred to are distinct from the mottled clays in point of age, that is to say, they do not coalesce, as might be thought at first sight. This is proved by their respective floras, that of the former being of a younger type (approaching more to that of the London Clay) than the latter. Whatever difficulties there may be in separating these two series of deposits at any particular place, this conclusive evidence is not thereby affected.

* On the occasion of the excursion to Plumstead, on the 16th July, 1887, under the direction of Mr. Goodchild, some Members of the Association were fortunate enough to discover the shells or casts of *Modiola*, *Pectunculus*, *Cyprina*, *Cytherea*, *Cardium*, and *Ostrea* in this bed at Plumstead Station.

† See Prestwich, 'Q. J. G. S.,' Vol. vi (1850), p. 264.

The pebble-bed at Croydon (3), and its equivalents in the Charlton (3) and Upnor (3) sections, contain fossils which are practically the same as those of bed 4. It is true that a few more marine types are found in it than in bed 4, yet anyone who has worked in the two beds is aware of the fact that the general facies of the one is exactly that of the other—*Cyrena*, *Melania*, and *Ostrea* being the common fossils in both.* Both beds get more marine in character as they go eastwards. A point of interest is that in the Upnor section the pebble-bed is rather weakly developed. In some parts of the section, indeed, it is altogether missing, and I believe it practically disappears before getting to East Kent, a few scattered pebbles only being developed. At Herne Bay bed 2 contains hardly any but marine fossils. I have found *Cyrena cuneiformis*, however, from it, in the collection of Mr. W. J. Abbott. With reference to the bed of sand with clay partings, found immediately under the London Clay at Croydon, Lewisham, and Bromley (bed 2), it contains a flora, which, so far as is known, is intermediate between those of the blue clays and the London Clay. The only beds with which we have not now dealt from a palæontological point of view are the sands and shingles forming bed 2 (p. 42) in the western part of the basin. So far as is known, these are marine in origin. Estuarine species have been found, but are exceedingly rare. Immediately under the London Clay the beds are sometimes very fossiliferous, being decidedly marine. One is inclined to think, however, from their intimate association with the mottled clays, that some of the sands just above the clays are of fresh-water origin, or at least estuarine.

We will now endeavour to show how the beds between the London Clay and the Chalk have been correlated. In doing so, we will chiefly consider the views of Prof. Prestwich, Mr. Whitaker, and Mr. Gardner. The first-mentioned observer, as before stated, laid the foundations of the study of these Lower Eocenes, and the manner in which he divided the beds, as contrasted by the later classification of Mr. Whitaker, may be conveniently expressed by the following table :—

* It may here be mentioned that Mr. Searles Wood ('Mon. Pal. Soc. Eocene Mollusca, Bivalves,' Supplement) calls into question the existence of *Cyrena britannica*, Sow., as he had never seen the shell. Mr. Jas. T. Day has obtained a perfect specimen, whilst I have found four fragments of it in the sand at the base of the pebble-bed (3) at Charlton.

Prof. Prestwich, 1850-54.			Mr. Whitaker, 1866.*	
London Clay.		Clay.		
Lower London Tertiaries.	Basement Bed of the London Clay.	*a.* Thin pebbly loam, &c., of the western part of the London Tertiary District.	Basement Bed.	London Clay.
		b. Thin clayey pebble-bed of Lewisham, &c.		
	Woolwich and Reading Series.	*c.* Highest sands of Upnor, the Reculvers, &c., with pebbles at the bottom.	Oldhaven (and Blackheath) Beds.	Lower London and Kentish Tertiaries.
		d. Part of the sandy pebble-bed of Kent (Blackheath, Abbey Wood, Shottenden Hill, &c.).		
		e. Part of the sandy pebble-bed of West Kent (Sundridge, near Bromley).		
		f. Sands, shell-beds, mottled clays, lower pebble-beds (unfossiliferous and local), and pebbly green sands of West Kent, and part of East Kent.	Woolwich and Reading Beds.	
		g. Mottled plastic clays, sands, &c., of the western part of the London Tertiary District and sands of East Kent.		
	Thanet Sands.	*h.* Sands, sandy marls, &c., &c.	Thanet Beds.	

Mr. Whitaker, as will be seen, created a new name (or names), the Oldhaven and Blackheath beds,† out of part of Prof. Prestwich's Basement Bed of London Clay and part of his Woolwich and Reading Series. His reason for so doing was his belief that the Oldhaven and Blackheath beds were both stratigraphically and palæontologically capable of separation, as a distinct series of deposits from the other beds. The irregularity of the Blackheath pebble-bed, which, he states, often cuts through several members of the underlying Woolwich and Reading Series (examples being cited from Greenwich, Bromley, Abbey Wood, &c.), lead him to think that an unconformity exists between that pebble-bed and the underlying series. He also believed that the sands below the

* 'Q. J. G. S.,' Vol. xxii, cited in Phillips' 'Manual of Geology,' by Robt. Etheridge, F.R.S. (1885), p. 607.

† 'Quart. Journ. Geol. Soc.,' Vol. xxii, p. 412.

London Clay at Herne Bay, &c., showed an assemblage of fossils distinct from those of either the Woolwich and Reading beds or the London Clay. A deposit of sands with clay partings at Bromley, which contains leaf-beds, was considered of fresh-water origin; and the pebble-bed, with estuarine fossils, at Charlton, and the marine sands of Herne Bay just alluded to, were all comprised in his Oldhaven beds. The Oldhaven and Blackheath Series were, therefore, of fresh-water, estuarine, and marine origin. He thought that the pebble-bed in the series was formed, not on a mainland beach, but a little way out at sea. He also says that the Woolwich beds sometimes lie on eroded surfaces of the Thanet beds, that the upper members of these Lower Tertiaries often overlap the lower ones, and that there is no stratigraphical unconformability between the Thanet beds and the Chalk. The lowest member of the Thanet Series, he says * is the bed containing the unrolled green-coated flints, which is remarkably persistent throughout the basin, and he believes that it may have been formed after the deposition of the beds above by the dissolving away of the Chalk by percolating water and the consequent leaving behind of its contained insoluble flints. Prof. McKenny Hughes † and others have written also on this subject. Mr. Whitaker is also of opinion that the Woolwich and Reading strata are so intimately associated with each other that it is impossible to separate the two series.

Mr. Gardner, on the other hand, maintains ‡ that the Oldhaven beds of East Kent should be added to the London Clay, being merely a lower member of the latter Series, as was implied by Prof. Prestwich's name for them ("Basement-bed of London Clay"). The most remarkable thing, however, is that Prof. Prestwich brackets his "basement-bed" not with the London Clay, but with the beds below to form the "Lower London Tertiaries." Mr. Gardner says that "We see by the Survey list of fossils § that the fauna (of the Oldhaven beds) was intermediate between those of the London Clay and the Thanet beds, for only two species are now not known to range beyond it; seven of the species range downward only, 12 range both up and down, and 13 range upward only; so that it is united by 75 per cent. of its

* 'Mem. Geol. Surv.,' *op. cit.*, p. 56.
† 'Q. J. G. S.,' Vol. xxii, p. 402.
‡ 'Quart. Journ. Geol. Soc.,' *op. cit.*
§ 'Mem. Geol. Surv.,' *op. cit.*, Vol. iv, p. 579.

species with the London Clay and by 50 per cent. with the Thanet beds." The part of the classifications of Prof. Prestwich and Mr. Whitaker to which Mr. Gardner takes the most serious objection, however, is with reference to the bed immediately above the Thanet Sand of those observers. It is the bed which I have numbered 4 in the western part of the basin (p. 42) and 6 at Croydon, Upnor, and Herne Bay, and is called the "Bottom-bed" of the Woolwich and Reading Series by Mr. Whitaker and others. As has before been stated (p. 47), this bed is marine throughout its extent from Hungerford to Herne Bay, whilst the remaining part of the Woolwich and Reading Series, above it, is either fluviatile or estuarine. Both Prof. Prestwich and Mr. Whitaker agree that it is difficult to separate this "bottom-bed" from the Thanet beds in the east of Kent, but, on the ground that it lies irregularly on the Thanet, and is distinct from it lithologically in so many places in West Kent and in the London area, they think it should be classed with the Woolwich and Reading Series rather than with the Thanet. Mr. Gardner, however, is of opinion that, being of marine origin, like the Thanet beds, being so closely allied with the latter palæontologically, and the bases of separation, as defined by previous observers, being so slight, this "bottom-bed" should be classed with the Thanet beds. He says * that "Of 57 specifically determined bivalves of the Thanet Sands 13 pass into the so-called marine division of the Woolwich and Reading beds, while of 12 bivalves from the latter only two—*Cardium Laytoni*, Morr., and *Teredo antenautæ*, Sow.—do not pass down into the Thanet beds. If the Survey list is accurate there is thus no marked palæontological break in the marine series." Mr. Gardner also thinks that the Reading beds (mottled clay, &c.) can be distinguished from the Woolwich (blue clays, &c.) by means of their floras, there being no data furnished for comparison of their faunas, as the mottled clay contains no other fossils than plants. He believes that there is an unconformability between the Chalk and the Thanet beds, as "even the highest Chalk must have been greatly denuded before it was compressed into a solid rock;" that in pre-Thanet times, where the water was shallow enough to permit the growth of sea-weed on the Chalk, sediment would ultimately be deposited on such a sea-weed covered surface, and that this imbedded vegetable matter may well account for the

* *Op. cit.*, p. 205.

peculiar character of the blackish-green mud-like sediment in which the green-coated flints are found. This bottom bed, he observes, might, of course, belong to a very much older period than the rest of the Thanet beds.

We will now examine the various points that have been raised. To begin with the bed immediately above the Chalk (the bed of green-coated flints, &c.). I do not see how it can be classed with the Thanet beds, because inasmuch as the bed with flints is generally admitted to have been formed subsequently to the deposition of those beds by the action of percolating water on the Chalk containing the flints, it cannot possibly—if this theory be the correct one, and I think it is—be wholly of Thanet age. There is no reason why the bed of green-coated flints should not be forming even at the present day. I believe that it should be classed with the Cretaceous beds below. It is merely a case of the abstraction of certain portions of a deposit in a manner similar to that which has removed fossil shells and calcareous matter generally from many portions of the Thanet (and other deposits). In such a case the Thanet beds would still remain of Thanet age after such abstraction had taken place. There would be no *à priori* reason for placing the Thanet beds with any overlying series, simply because of the abstraction of a certain amount of lime. So also with these green-coated flints; the only difference being that a greater quantity, perhaps, of lime has been removed. It would be a different matter if the flints were the products of denudation. With regard to the green clay, &c., it appears to me to be largely the particles of impurities, &c., brought through the sand by the action of water, which on arriving at the Chalk was filtered, and so the particles were left behind. Some of it may be, and most probably is, the remains of insoluble matter, other than flint, which was contained in the Chalk itself. Moreover, such green clay, &c., is not present in any appreciable quantity in many sections showing the junction of the Chalk with the Thanet, although the green-coated flints almost invariably are. I do not include the bed numbered 7*a* (p. 45) in these observations. This may be regarded as the oldest Eocene bed in the London basin, so far as we know at present.

Coming now to the question of the correlation of the "bottom-bed" of the Woolwich and Reading Series of Prof. Prestwich and Mr. Whitaker, I am almost entirely of Mr. Gardner's opinion that

it should be removed from that series and placed in the Thanet beds, for the same reasons which he has advanced. There is only one suggestion which I would make, viz., that as the upper part of this so-called "bottom-bed" contains carbonaceous matter, especially at Herne Bay, it may be the representative of the bed numbered 5*c* at Upnor (see p. 44). It is in a corresponding position. If this be so, it is the equivalent of the mottled clay in the Herne Bay section.

The next point to which attention may be drawn is the correlation of the blue clays (4) in the Upnor section with the black ferruginous sandy-clays with sand partings in the Boughton-under-Blean district.

Every observer, so far as I am aware, agrees that the bed numbered 4 in the Croydon, Charlton, and Upnor sections is the Woolwich blue clay with fossils. After passing Upnor, however (going eastward), they assert that this blue clay dies out, the last place in which it is seen being in the neighbourhood of Sittingbourne. If this were the case it would not, of course, reach Boughton, as I have suggested. The bed numbered 4 in the sections of the last-mentioned district, and which I believe to be the eastward extension of this blue clay, is included in the basement bed of the London Clay by Prof. Prestwich,* and in the Oldhaven beds by Mr. Whitaker; † though it is difficult to see on what grounds. Everybody admits that there is a general tendency of the Lower Eocenes of the London basin to become more marine in character as they go eastwards; and I regard the black ferruginous clay and sand alluded to, as the more marine equivalent of the estuarine blue clays further westward. The bed at Boughton, as previously stated, still contains a large proportion of estuarine fossils mixed with marine. Not only is the palæontological evidence in favour of this view to a slight extent, but the lithological character of the deposit, and its position with reference to under and overlying beds are so also. It is true that the ferruginous clay is rather more arenaceous in some sections than in others, yet its argillaceous character is not obliterated, but, on the contrary, is well marked in some of the sections. As we have already seen (p. 45), the position of this ferruginous clay and sand, with reference to the sands and lilac-

* 'Q. J. G. S.,' Vol. vi (1850), p. 264.
† 'Mem. Geol. Surv.,' Vol. iv, pt. 1 (1872), pp. 266 8.

coloured sandstone below, is identical in both the Upnor and Boughton sections. Its horizon is, therefore, clearly shown. The ferruginous bed in question can be traced at intervals along the southern outcrop of the main mass to Canterbury, and is found at the latter place in the same position. The succession is equally clear at Herne Bay. It has also been shown (pp. 45-6) that the pebble-bed found below it at Herne Bay can be recognized also at Boughton and Canterbury. This pebble-bed bears no relation, I believe, to the pebble-bed (3) at Upnor, or the equivalent bed in the Charlton and Croydon districts. I differ on this point from previous observers, and my reasons are quite obvious from what has been said respecting it.

We now come to the consideration of the alleged unconformability of the pebble-bed on Blackheath to the beds on which it lies, examples of the irregularities of its occurrence having been cited (p. 43). It will be remembered that the creation of the Blackheath series is largely dependent on the value of the evidence afforded by this pebble-bed; and it is, therefore, of the first importance that the question of whether there is, or is not, an unconformability should be inquired into. It may here be mentioned that quite recently Mr. J. G. Goodchild* has strongly advocated the existence of a stratigraphical break between the Woolwich and Reading Series and this pebble-bed. He furthermore (in common with others) considers that the palæontological break between the Chalk and the Thanet beds is not so great as has generally been supposed. With this last remark I am rather inclined to agree, because it is obviously unfair to compare the fauna of a limestone with that of a sand. The fauna of the Thanet beds ought strictly to be compared with that of the Upper Greensand, but the latter is so far removed by reason of the interposition of the Chalk that it is difficult to realize this, whilst the evolution and migration of the species has been such as to render the comparison somewhat unfruitful. At the same time, although we may believe that the palæontological break at this point has been overrated, it is quite marked enough to enable us to draw a line between the Chalk and the Thanet, in preference to any other horizon, to separate the Secondary from the Tertiary beds. We have already seen that there is other evidence indicating an unconformability between the two formations alluded to, and if anything further is desired it is

* 'Proc. Geol. Assoc.,' Vol. ix, pp. 213-214.

only necessary to point to the beds deposited in Belgium, close by, between the equivalents in that country of our highest Chalk and our Thanet beds. We shall then find that the Maestrichtien, Tufeau de Ciply, &c., and Calcaire grossier de Mons were deposited in the interval. Surely, the evidence is conclusive enough.

And now as to whether the Blackheath pebble-bed is unconformable or not to underlying deposits. In considering a question of this nature, we have, in the first place, to be quite sure that we are dealing with a pebble-bed the exact horizon of which is known. Now, can the horizon of the pebble-bed stretching from Greenwich by Blackheath to Plumstead and Erith be correctly ascertained? We must remember that the bed alluded to lies mostly at the surface, and it is in this position that it chiefly presents the phenomena of cutting into other beds. In many of these cases it is unfossiliferous, and in others it appears to me that it is impossible to fix its exact horizon. It is generally assumed by the surveyors that the pebble-bed occurs below their "basement bed of the London Clay," and in some cases this may be correct. It will be as well to point out, however, that pebble-beds occur on other horizons in these Lower London Tertiaries in the same district as that now under consideration, and that it is not at all times clear which of these pebble-beds crop out on the hill-sides, though such, on coming to the surface, are generally recognized as the Blackheath pebble-bed. At least three different pebble-beds are found in the strata hereabouts, the first being immediately at the base of the London Clay as at Loam Pit Hill, Lewisham; the second in the sand with clay partings above the blue clays;* and the third at the top of the Thanet beds in the Loam Pit Hill section.† Whether all the surface pebble-beds were formed in the Lower Eocene period is also a moot question. Pebble-beds of a similar nature do occur in the Bagshot and subsequent deposits. Another element which creeps in is as to how far some of the shingle has been slightly shifted by various agencies in recent times. Many of the pebble-beds between Greenwich and Erith suggest this, and they lie at suspiciously high angles on the hill slopes. But even supposing that the assumed horizon of these surface pebble-beds is the correct one, and not open to doubt as I have suggested, I cannot think that the mere circumstance of an

* Well developed in a section over the railway tunnel at Charlton.

† 'Mem. Geol. Surv.,' *op. cit.*, p. 127, beds 10 and 11.

estuarine pebble-bed having cut its way through a few feet of deposits, and resting irregularly on another and lower deposit, is sufficient grounds for showing an unconformability. The very action which brought a pebble-bed to the spot at all, would have been quite capable of scooping out such light sandy materials. It might be otherwise if we were dealing with a series of purely marine beds. The deposits under consideration, as pointed out, are estuarine in origin, and are regarded as the delta of an enormous river. Everybody is aware of the irregularities of river and estuary deposits, which are largely dependent in their development on the velocity of the stream at different periods. Heavy rainfalls in the river-basins are powerful agents in effecting these changes. Is it because a very rainy season renders the river suddenly more turbulent than ordinary, and causes a rather abnormal amount of irregularity in the deposits; or because the silt chokes up one of the mouths of the river so that it eventually bursts through in a new place, or enlarges a little-used channel, that the result is an unconformability, and one, too, of such magnitude as to involve the creation of a distinct geological formation? A study of the works issued in recent years by the United States Geological Survey * soon convinces us of the character and appearance presented by the deposits of rivers and lakes of great magnitude; and if an unconformability were to be drawn at every such irregularity there would be endless confusion. In some cases, no doubt, where palæontology demands it, such a break may be conveniently made, but in the case of the Blackheath pebble-bed now before us there is no such demand. The fossils are almost identical with those of the Woolwich and Reading Series below, and there is, therefore, no reason for separating the two deposits from each other.

Turning to the Oldhaven Sand of Mr. Whitaker. We have seen that palæontologically it is intermediate between the Thanet beds and the London Clay (see p. 50), and have also seen its position with reference to the black clays. I should not have much hesitation in correlating it with the London Clay, as does Mr. Gardner, except that no passage bed is observable in the Herne Bay section, where they are best examined. On the contrary, the base of the London Clay is very lignitic at that point, and is sharply marked off from the sand alluded to. All these things tend to show that there is no gradual passage between

* *e.g.*, 'Mon. U. S. Geol. Surv.,' Vol. xi (1885).

the sand and the clay, as should be the case if this sandy bed is to be regarded as an integral part of the London Clay formation. At the same time I do not apprehend that there is a break of any importance; but, as both the palæontological and stratigraphical evidence seem in favour of it, we may class this bed with the Woolwich and Reading Series;* and I believe it is, therefore, together with the argillaceous and pebble-beds below, the marine representative of that series in East Kent. The only divisions of the Lower Eocenes, therefore, that seem to me admissible in the London basin are:—

1. London Clay.
2. Woolwich and Reading Series.
3. Thanet Series.

With regard to the Lower Eocenes of the Hampshire basin, we know so little about the lowermost members that it is safe to adhere to the present nomenclature, though the sand resting on the Chalk in some places suggests the occurrence of the Thanet Sand in that area. We find that the London Clay is present in force, that the so-called "Oldhaven and Blackheath" beds are missing, whilst the mottled clay is exceedingly well developed.

Mr. Gardner's masterly researches in the Lower Eocenes of the Isle of Mull have been so recently recorded at the Geological Society that his paper is not yet issued to the public.† It would be superfluous for me to mention more than that he has demonstrated, from a careful study of the fossil plants imbedded between sheets of basalt, &c., in that island, that Eocene beds are present, and that some of them, indeed, are older than the Thanet beds of the London basin. This is by far the most important addition to our knowledge of this period which has been made in recent years.

The same observer has also shown that Lower Eocene beds exist in Antrim, in north-east Ireland; and I would refer to his memoirs "On the Age of the Basalts of the North-east Atlantic" ('Proc. Belfast Nat. Field Club,' Ser. ii, Vol. ii, Part IV, 1883-4); "On the Evidence of Fossil Plants regarding the Age of the Tertiary Basalts of the North-east Atlantic" ('Proc. Roy. Soc.,' No. 235, Dec. 18, 1884); and on "The Lower Eocene Plant-beds of the

* The possibility of this being the case was, I find, suggested by Prof. Prestwich, 'Q. J. G. S.,' Vol. x (1854), p. 130.

† Since published, 'Q. J. G. S.,' Vol. xliii, Part II, May, 1887.

Basaltic formation of Ulster" ('Q. J. G. S.,' Vol. xli, 1885, p. 82) for further details. The beds are chiefly of the age of the Heersien beds of Belgium, which, as I have elsewhere attempted to show,* are of the same age as the lower part of our Thanet beds. We may look forward with interest to the further investigation of these Irish and Scotch Eocenes.

ORDINARY MEETING.

FRIDAY, APRIL 1ST, 1887.

F. W. RUDLER, F.G.S., Hon. Sec. Anthrop. Inst., President, in the Chair.

The donations to the Library since the previous meeting were announced, and the thanks of the Association accorded to the various donors.

The following were elected Members of the Association :—

Captain W. Ashby; A. Cates; J. W. Dale; H. G. Erith; Rev. E. Hill, M.A., F.G.S.; H. E. Jones; H. W. Sich.

The following paper was then read :—

'On the metamorphosis of basic igneous rocks.' By J. J. H. Teall, M.A., F.G.S.

The paper was illustrated by lantern slides (many of which were photographs taken by Mr. Barrow) and by hand specimens.

THE METAMORPHOSIS OF BASIC IGNEOUS ROCKS.

BY J. J. HARRIS TEALL, M.A., F.G.S.

An igneous rock may be said to attain individuality at the time of final consolidation. Many minerals which enter into its composition may have been formed previously, but the birth-time, so to speak, of the rock is the time when the last portions of molten matter solidify. So long as the rock remains subject to the conditions which prevailed at the moment of final consolidation, it is in a state of stable equilibrium. These conditions do not, however, remain constant, as a rule, for any considerable length of time, and accordingly we find that the rock in adapting itself to the changed conditions, or, in other words, in adapting itself to its environment, undergoes important modifications in structure and composition. As we examine it, the rock is not in its original condition; it has been more or less metamorphosed.

* 'Geol. Mag.,' Dec. 3, Vol. iv (1887), p. 108.